MPMS® 3

# MPMS 3 Platform Measurement Options

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# MPMS® 3

Quantum Design's Magnetic Property Measurement System, MPMS 3, represents the culmination of 40 years of development and design. The MPMS 3 provides users with the sensitivity of a SQUID (Superconducting QUantum Interference Device) magnetometer and the freedom to choose multiple measurement modes. Users will experience new levels of performance while still enjoying the capabilities of past Quantum Design SQUID magnetometers that they have grown to appreciate and depend on.

Quantum Design's award-winning MPMS 3 also provides expanded software functionality within its user-friendly MultiVu interface. By combining major advances in data acquisition speed, temperature and magnetic field control, and a measurement sensitivity of ≤ $10^{-8}$ emu, the MPMS 3 truly represents the next generation of advanced SQUID magnetometry.

## Specifications

### MPMS 3*

| | |
|---|---|
| Cabinet Power Requirements: | 200 to 230 VAC, 50/60 Hz, 10 A Max |
| Liquid Helium Usage: | 4 liters/day (typical)** |
| Liquid Helium Capacity: | 70 liters |
| Liquid Nitrogen Usage: | 5 liters/day (typical) |
| Liquid Nitrogen Capacity: | 60 liters |

* Specifications apply to non-EverCool® base configuration.
** Liquid helium consumption increases with cooldowns, field ramps, and oven usage.

Specifications are subject to change without notice.


MPMS®3

# MPMS® 3 EverCool®

The Quantum Design MPMS 3 EverCool upgrade removes the need for liquid helium transfers and virtually eliminates all helium loss. From the user's perspective, the integrated pulse-tube cryocooler and specialized dewar system can be considered cryogen free as it accomplishes the initial cool-down from helium gas and subsequently recondenses helium boil-off into liquid directly within the dewar.

The MPMS 3 EverCool is available as an option for the Quantum Design MPMS 3. The complete system requires the use of a water chiller for the water-cooled compressor, as well as an external helium gas supply.

## MPMS 3 EverCool advantages:

- Minimal additional space requirements for the cryocooler compressor
- Production of initial operating charge of liquid helium from helium gas in less than 50 hours
- Full integration of all EverCool functions within the MPMS 3 MultiVu software environment, allowing automatic system operations including the initial system cooldown and helium level control

The EverCool configuration utilizes a permanently running cryocooler, which has been engineered to have no influence on the system measurement specifications. The noise performance is identical to the standard MPMS 3 base system.

## Specifications

### MPMS 3 EverCool

| | |
|---|---|
| Helium Liquefaction Rate: | ~5 liters/day* |
| Nominal LHe Capacity: | ~16 liters** |
| Estimated Cool-Down Time: | <50 *** |

**Physical Configuration and Dimensions**

| | |
|---|---|
| Main Cabinet (excl. keyboard arm and compressor hoses): | ~84 x 104 x 199 $cm^3$ (L x W x H); Weight: ~400 kg. |
| Pump Console: | ~71 x 61 x 61 $cm^3$ (L x W x H); Weight: ~65 kg. |
| Compressor: | ~46 x 48 x 62 $cm^3$ (L x W x H); Weight: ~120 kg. |
| Compressor Hoses (pair): | ~ 20 m length; Weight: ~ 35 kg (pair) |

**Water-Cooled Compressor Configurations & Power Requirements**

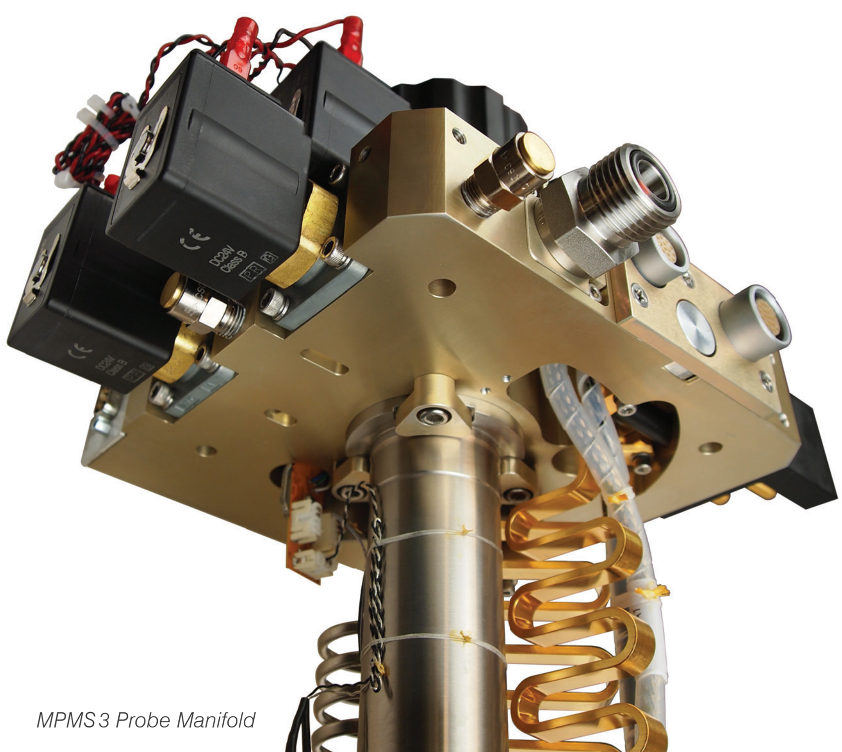
| | |
|---|---|
| Compressor Configuration: | 3 Phase required<br>*Consult with your local sales/service representative regarding voltage and current configurations.* |
| Power: | 9 kW max with a typical consumption of 7.2 kW |
| Cooling Water Requirement: | ≥ 4 gal/min @ 28 °C and ≥ 2.5 gal/min @ 10 °C |

**Recommended Maintenance Intervals**

| | |
|---|---|
| Compressor: | After 20,000 operational hours |
| Cold Head: | After 30,000 operational hours |

*This represents the amount of liquified helium that can be generated in excess of the normal daily system usage.
**Full capacity is defined when the level reaches the bottom of the vapor cooled magnet.
***An addtional 20 hours are necessary to reach the nominal LHe level.

Specifications are subject to change without notice.



*MPMS 3 Probe Manifold*

# Field/Magnet Control

## Standard Magnet

The MPMS 3 utilizes a 7 T, superconducting, helium vapor-cooled magnet and a hybrid digital/analog magnet power supply. Both are optimized for precise and quiet control of the magnetic field, critical for ultra-sensitive SQUID-based magnetometry. The use of high-temperature superconducting magnet leads aids in lowering the instrument's helium consumption.

The MPMS 3 accomplishes rapid switching between charging/discharging and stable fields with a unique, patented superconducting switching element (QuickSwitch™) which changes between superconducting and normal states in less than one second. Furthermore, the low thermal mass of the MPMS 3 QuickSwitch also helps to minimize liquid helium consumption.

The MPMS 3 features an integrated magnetic shield. This shield not only facilitates sensitive measurements by creating a locally quiet environment, it also serves as a return path for the field lines of the system's superconducting magnet. Therefore, the MPMS can be placed in close proximity to other sensitive equipment due to its low stray field

## Ultra-Low Field (ULF)

The MPMS 3 ULF option actively cancels the residual magnetic flux in the superconducting solenoid to less than ±0.05 G. This capability is extremely important for measurements of superconductors and spin glasses, which require collecting data in zero field for proper characterization. In addition to enabling zero-field measurements, the option also allows one to set field up to ±20 G with a resolution better than two orders of magnitude compared to a standard system, which can be useful in the study of ferromagnets with small coercivities.

The ULF option incorporates additional electronics and a fluxgate magnetometer. In basic operation the fluxgate first measures the residual field profile along the solenoid's longitudinal axis. Then the in-situ modulation and trim coils null the field to the desired setpoint and uniformity, which is then confirmed by the fluxgate.

### Standard Magnet Specifications

**Magnetic field control**

| | |
|---|---|
| Superconducting Switch: | QuickSwitch™ |
| Magnetic Field Range: | -70 kOe to +70 kOe |
| Field Uniformity: | 0.01% over 4 cm |
| Field Charging Rate: | 4 Oe/sec to 700 Oe/sec |
| Field Charging Resolution: | 0.5 Oe (typical) |
| Remanent Field: | ~5 Oe (typical) when oscillating from full field back to zero |

### Ultra-Low Field Specifications (M355)

**Nulling Specifications**

| | |
|---|---|
| Field Nulling Window[1] | Up to ± 10 mm |
| Field Uniformity[2] | ± 0.05 G |
| Target Field Range[3] | ± 5 G |
| Field Stability[4] | 24 hours |

**Fluxgate Specifications**

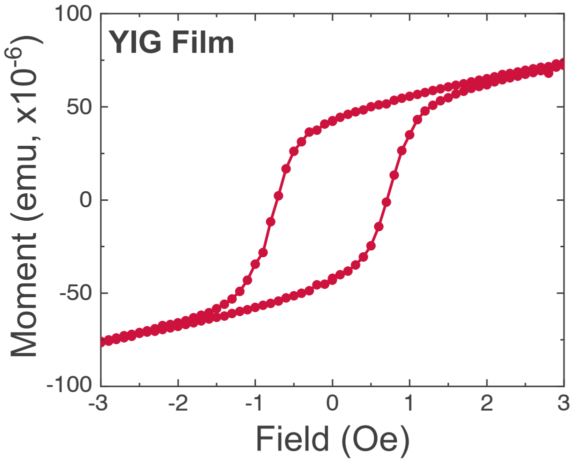
| | |
|---|---|
| Fluxgate Range[5] | ± 10 G |
| Sensitivity[6] | ± 0.002 G |
| Accuracy: | ± (0.02 G + 0.5% measured field) |

**Additional Specifications**

| | |
|---|---|
| Magnet Profiling Length[7] | Up to 50 mm |
| High Resolution Field Range[8] | ± 20 G |
| Field Resolution: | Better than 0.002 G |
| Field Accuracy: | ±(0.002 G + 0.5% set field) |

Specifications are subject to change without notice.

[1] Window in which field is nulled (distance from magnet center).
[2] Maximum field at any point along the magnet axis inside the nulling window.
[3] Any target field within this range can be set with quoted uniformity and verified via fluxgate.
[4] Stability (within uniformity specification) over time of the applied field.
[5] Field range which can be read by the fluxgate.
[6] Intrinsic noise of fluxgate reading.
[7] Maximum length along magnet axis which can be profiled using the fluxgate.
[8] High resolution field range which can be applied by the option.




*Hysteresis loop of a YIG film with a coercivity less than 1 Oe measured using the SQUID-VSM detection mode and ULF capabilities.*

# Temperature Control

The MPMS 3 uses an innovate temperature control design that allows samples to be cooled from room temperature to a stable 1.8 K in less than 30 minutes.

The temperature control insert utilizes a vacuum-insulated chamber into which cold helium is drawn through a variable flow valve. A finely tuned flow impedance and sophisticated control software allow continuous operation at 1.8 K as well as smooth temperature control through the liquid helium boiling point at 4.2 K. Heaters allow for operation up to 400 K and the thermal shield minimizes liquid helium consumption when operating at elevated temperatures.

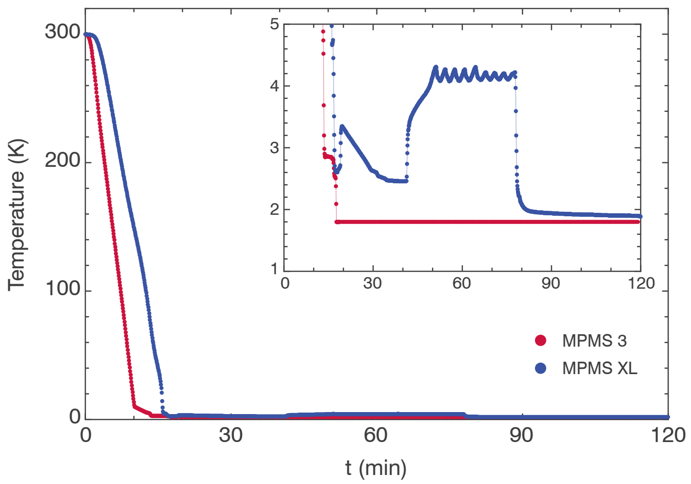
By flattening the thermal gradient along the cold end of the temperature control insert, the thermal shield also allows the entire insert to be constructed with a much shorter geometry than prior MPMS generations, thus minimizing heat capacitance and enabling rapid temperature control.

The 9 mm diameter sample chamber bore enables the smallest diameter pickup coils possible, optimizing the sensitivity of the magnetometer.

### Temperature Control Specifications

| | |
|---|---|
| Operating Range: | 1.8 K to 400 K |
| Cooling Rate: | 30 K/min (300 K to 10 K stable in 15 min., typical); 10 K/min (10 K to 1.8 K stable in 5 min., typical) |
| Temperature Stability: | ± 0.5% |
| Temperature Accuracy: | lesser of ±1% or 0.5 K |
| Sample Chamber I.D.: | 9 mm |

Specifications are subject to change without notice.




*Cooling performance from room temperature of the MPMS 3 compared to the MPMS XL obtained by directly setting the system's base temperature at a fast rate. Note that in addition to reaching temperature stability much faster, the temperature history is completely monotonic for the MPMS 3 (see inset).*

# Sub-Kelvin Capabilities

## iQuantum He3

The iQuantum He3 option extends magnetic property measurements down to 0.42 K.

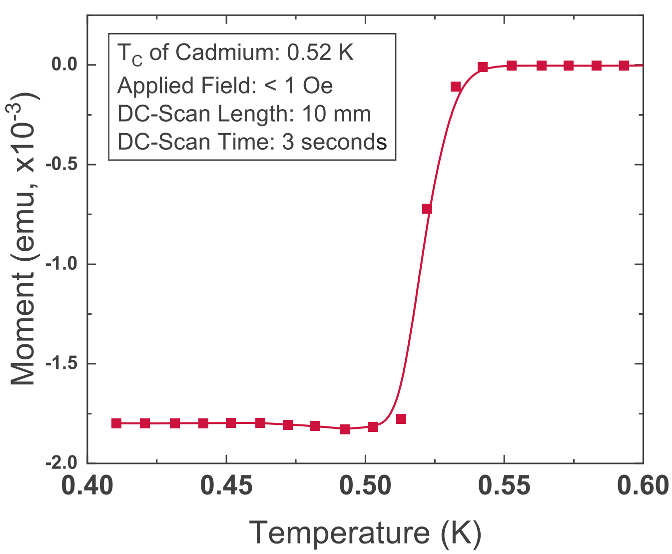
The He3 option consists of a stand-alone controller, an insert installed within the MPMS 3 sample space, and control software integrated with the base MPMS 3 system. Samples are mounted on a specific He3 sample holder which includes dedicated thermometry for accurate sample temperature monitoring and control. The He3 sample holder is top-loaded into the insert and magnetically coupled to the MPMS 3 sample transport.

### The He3 sample cooldown process:

- Evacuate air from the sample region
- Introduce He3 gas into the sample region
- Cool the MPMS 3 down to its base temperature and wait for the He3 gas to condense
- Begin pumping on the condensed He3 for temperature control

### Key Features:

- 0.42 K to 1.8 K temperature range
- EverCool® compatible
- DC Scan and AC susceptibility measurement modes only
- Uses traditional straw mounting




*Superconducting transition of Cadmium.*

### iQuantum He3 Specifications

| | |
|---|---|
| **Temperature** | |
| Operational Range: | 0.42 to 1.8 K; 0 to 7 T |
| Temperature Stability: | ± 1% |
| Temperature Accuracy*: | 2% |
| **Cooldown Time:** | 300 K to 0.5 K in less than 3 hours |
| **He3 Performance** | |
| He3 Gas Volume: | 3 liters |
| He3 Lifetime** (typical): | 20 hours |
| He3 Lifetime** (Base Temperature): | 40 hours |
| He3 Recondense Time (typical): | < 30 minutes |

*Based on $T_c$ of Cadmium reference sample.

**Typical operating time before recondensing the He3 gas is necessary.

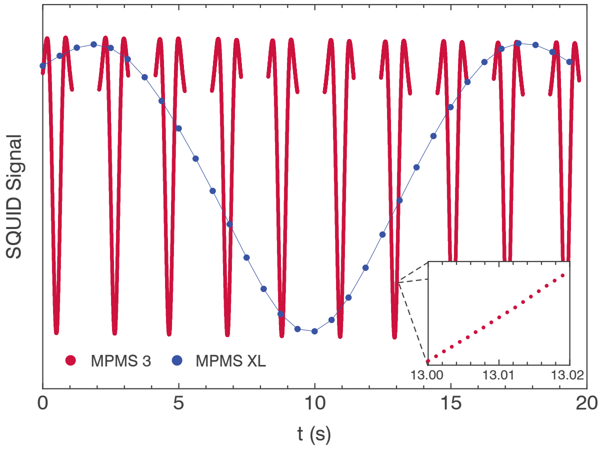
Specifications are subject to change without notice.

# Measurement Modes

## DC Measurement Modes

### Traditional DC Scan

- Standard measurement mode included with all MPMS 3 systems
- 10x faster data acquisition compared to MPMS-XL
- Ideal for measurements using the rotator, FOSH, pressure cell, and iQuantum He3




*Significantly increased speed and point density of the new DC Scan Measurement Mode of the MPMS 3 compared to a standard DC scan acquired on the MPMS XL. The increased point density and shorter acquisition time allow for better rejection of noise and SQUID drifts as well as more data points for analysis of the raw data.*

### SQUID-VSM

- Improved sensitivity and rapid data acquisition compared to the DC Scan mode
- 0.1 to 8 mm oscillation amplitude enables a large dynamic range
- Highly insensitive to non-linear SQUID drift
- Measurements occur in a more uniform temperature and magnetic field

### DC Moment Specifications

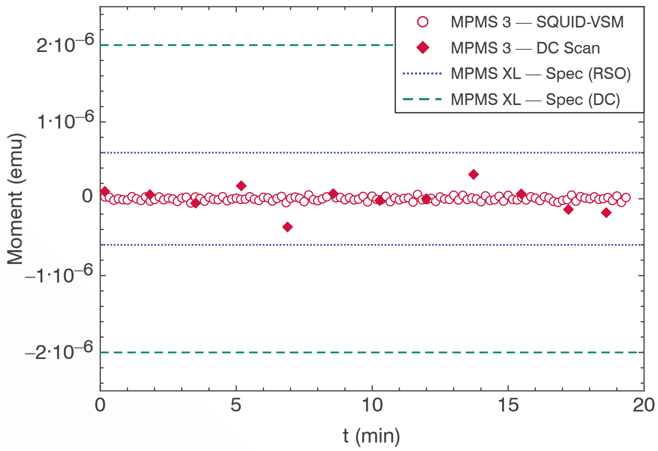
**DC Scan**

| | |
|---|---|
| Sensitivity: | $< 5 \times 10^{-8}$ emu (H $\leq$ 2,500 Oe), $< 6 \times 10^{-7}$ emu (H $>$ 2,500 Oe) |
| Maximum Moment: | 2 emu (typical) |

**SQUID-VSM** (M325)

| | |
|---|---|
| Sensitivity: | $< 1 \times 10^{-8}$ emu (H $\leq$ 2,500 Oe), $< 8 \times 10^{-8}$ emu (H $>$ 2,500 Oe) |
| Maximum Moment: | $>$ 100 emu |

Specifications are subject to change without notice.




*The MPMS 3 provides the lowest noise floor ever available in a Quantum Design SQUID magnetometer (both for DC Scan and SQUID-VSM measurement modes). MPMS 3 noise data was collected at full field on an EverCool equipped system with the cold head running.*

*The brass trough sample holder is ideal for samples with cylindrical symmetry and is compatible with the powder sample holders.*

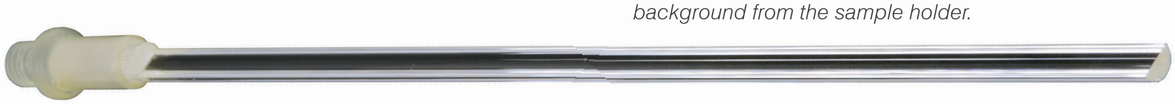
# Measurement Modes

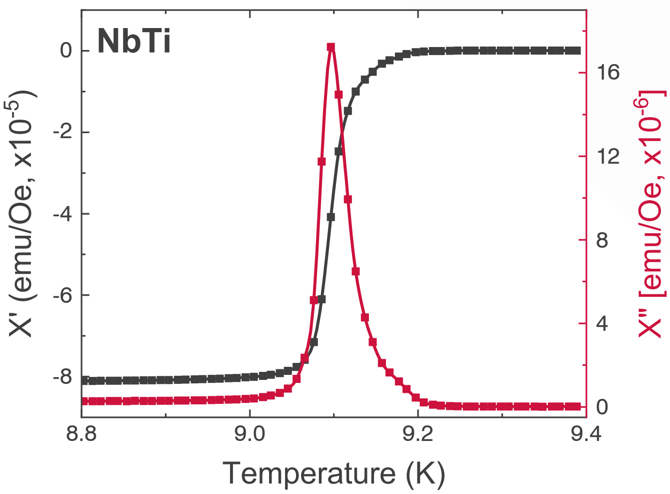
## AC Susceptibility

The AC Susceptibility option measures the dynamic response (real/imaginary or amplitude/phase) of a wide variety of samples including superconductors, spin glasses, nanoparticles, single-molecule magnets, etc.

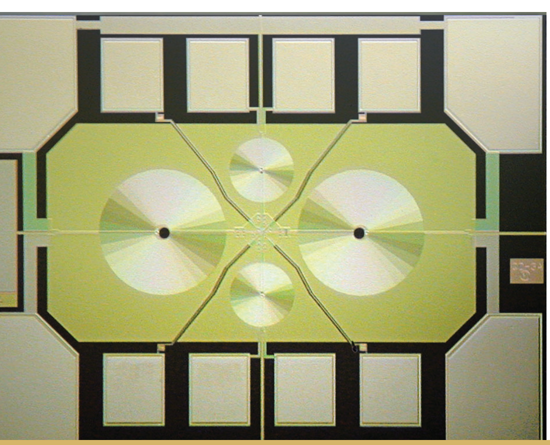
- AC Frequency Range: 0.1 to 1000 Hz
- AC Field Amplitude: 0.1 to 10 Oe

*The quartz paddle sample holder is ideal for mounting small single crystals, pelletized powders, and thin films. As It is also electrically insulating, it is well-suited for performing AC susceptibility measurements with minimal background from the sample holder.*






*Real (black) and imaginary (red) components of the AC susceptibility highlighting the superconducting transition of NbTi.*



### AC Susceptibility Specifications (M350)

| | |
|---|---|
| AC Frequency Range: | 0.1 Hz to 1 kHz |
| AC Amplitude[1] (Peak) | 0.1 Oe to 10 Oe |
| AC Moment Sensitivity[2,3] | $\leq 5 \times 10^{-8}$ emu (typical) |
| AC Moment Accuracy[4] | $\leq \pm 1\%$ (typical) |
| Phase Angle Accuracy[3,5] | $\leq \pm 0.5^\circ$ (typical) |

**Frequency[6] and Temperature[7] dependencies**

| | |
|---|---|
| on AC Moment: | $\leq \pm 1\%$ (typical) |
| on Phase Angle: | $\leq \pm 0.5^\circ$ (typical) |

AC measurements can be performed in the full parameter space (temperature, dc magnetic field) of the base system as well as with the oven option, although to different specifications. For more details on using the oven and AC options together, visit www.qdusa.com/techsupport and refer to the MPMS 3 Application Note 1505-001.

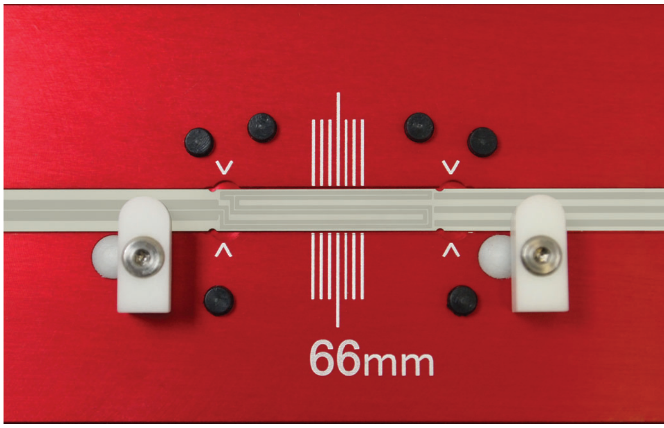
Specifications are subject to change without notice.

[1] Maximum drive amplitude is frequency dependent. Software will dynamically reduce the maximum amplitude at higher frequencies.
[2] Smallest moment change that can be detected.
[3] Specification defined for a moment of about $5 \times 10^{-6}$ emu using reference sample at 300 K with 10 Hz AC frequency and 10 s averaging.
[4] Reported AC susceptibility for reference sample agrees with measured DC susceptibility. Specification defined using reference sample at 300 K, DC susceptibility extracted from DC MvsH measurement between $\pm 100$ Oe with 5 Oe field steps, AC susceptibility measured at 10 Hz with 10s averaging and an AC amplitude to give moment of at least $2 \times 10^{-5}$ emu.
[5] Reported phase angle for reference sample agrees with expected value.
[6] Frequencies spanning 0.1 Hz and 1 kHz for AC moments larger than $2 \times 10^{-5}$ emu.
[7] Temperatures between 2 K and 400 K for AC moments larger than $2 \times 10^{-5}$ emu.

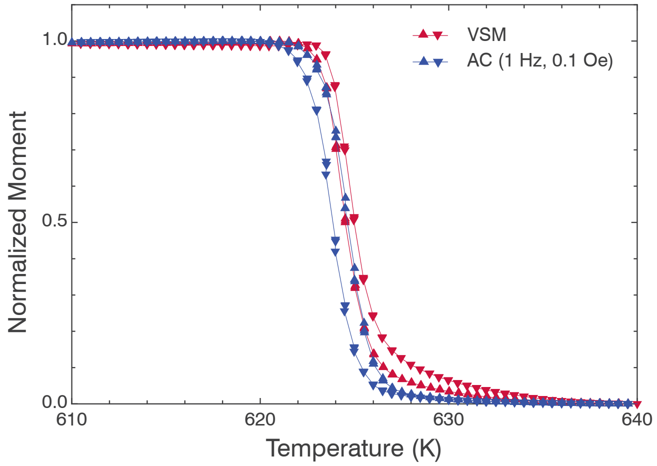
# High Temperature

## Oven

The MPMS 3 Oven option extends the accessible temperature range for magnetic property measurements up to 1000 K. A specialized sample holder both locally heats the sample and measures the temperature. Measurements of the DC moment via both DC Scan and SQUID-VSM measurement modes as well as low-frequency AC susceptibility are all possible with the Oven option.




***Detail:** MPMS 3 oven sample mounting platform with oven sample holder.*




*Measurement of the magnetization as a function of temperature for a small piece of nickel to examine the Curie temperature using both the VSM and AC measurement techniques with the oven option. 0.5 K step sizes, stabilizing temperature and a 10 Oe applied magnetic field were used to collect the data.*

### Oven Specifications (M303)

| | |
|---|---|
| Temperature Range: | 315 K to 1000 K |
| Temperature Accuracy: | Better than 2% after stabilizing |
| Temperature Stability: | ± 0.5 K |
| Moment Sensitivity: | 1.0 x $10^{-6}$ emu<br>(H ≤ 2500 Oe, T = 300 K, 10 s averaging)<br>8.0 x $10^{-6}$ emu<br>(H > 2500 Oe, T = 300 K, 10 s averaging) |

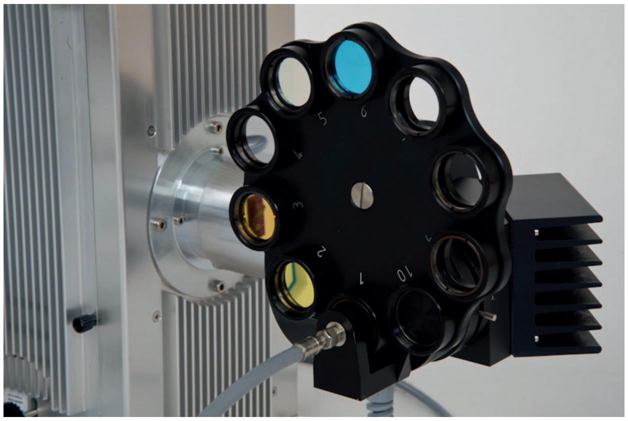
### Sample Holder Specifications

| | |
|---|---|
| Overall dimensions: | 160 mm (L) x 5 mm (W) x 0.5 mm (H) |
| Heater region: | 25 mm (L) x ~5 mm (W) in center of holder |
| Sample mounting location: | 66 mm from bottom of holder |
| Max. sample thickness: | 1 mm |

Specifications are subject to change without notice.

# Magneto-Optic Measurement Capabilities

Quantum Design provides a specialized Fiber Optic Sample Holder (FOSH) optimized for either the UV or IR bands. Additionally, two light sources are available for sample illumination. The MLS Xenon Light Source produces white light which can be filtered down to a specific wavelength using a manually rotated filter wheel, while the TLS120Xe can be tuned automatically with software commands in MultiVu across an even wider range. Both sources output to a standard SMA-style connector and have user-replaceable lamps.



*MLS Xenon Light Source shown with the 10-position filter wheel used to produce monochromatic light.*

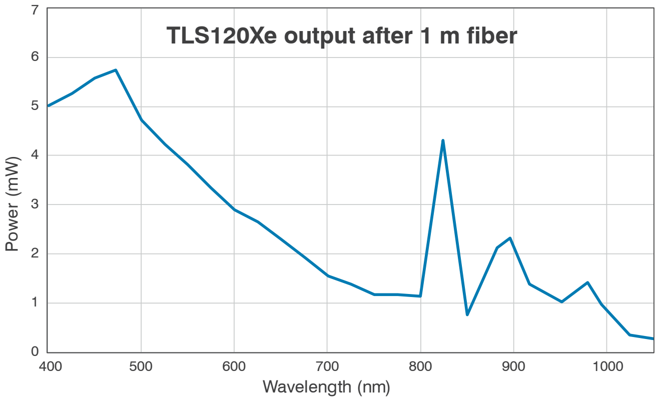
*Fiber Optic Sample Holder (FOSH)*

*Sample cup and lid*

*Fiber optic insert*

*FOSH sample rod*


*TLS120Xe with manual front panel controls active*




*Typical power spectrum of the TLS120Xe denoting approximate radiant flux incident on a sample as a function of wavelength.*

## Light Sources Specifications

**TLS120Xe** (M312)

| | |
|---|---|
| Wavelength Range: | 280 to 1100 nm |
| Bandwidth: | 20 nm (FWHM) |
| Grating Line Density: | 1200 lines/mm |
| Nominal Blaze Wavelength: | 380 nm |
| Lamp Type: | Short-arc OFR xenon (100 W) |
| Lamp Lifetime: | 500 hours |

**MLS Xenon Light Source** (M326)

| | |
|---|---|
| Wavelengths (FWHM): | 436 nm (20 nm), 470 nm (40 nm), 500 nm (20 nm), 530 nm (30 nm), 555 nm (20 nm), 585 nm (40 nm), 640 nm (30 nm), 740 nm (40 nm), 850 nm (40 nm) |
| Lamp Type: | Short-arc xenon (300 W) |

**Fiber Optic Sample Holder (FOSH)** (M320)

Specifications are subject to change without notice.

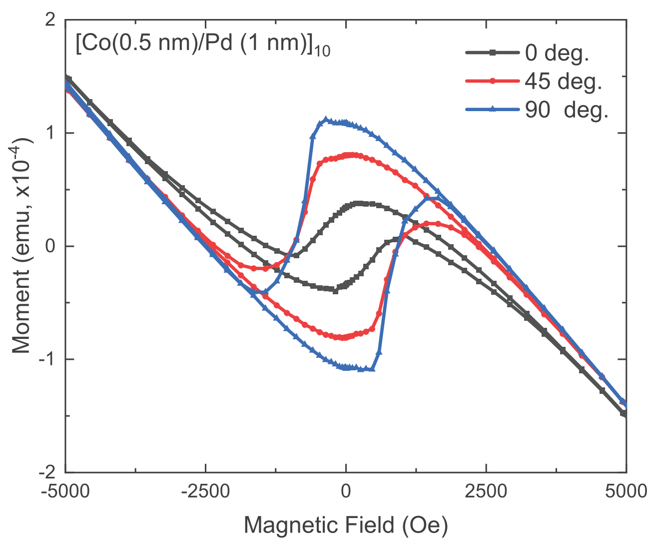
# Rotator

The MPMS 3 Rotator allows for in situ rotation of samples and is compatible with the DC-Scan mode only. Two sample holders are included. The in-plane sample holder is ideal for small single crystals and measurements of thin films where the applied field direction should be varied over angles within the film plane. The out-of-plane sample holder is also ideal for single crystals and thin films where the applied field direction should be varied over angles perpendicular to the film plane.

*In-Plane: Ideal for small single crystals or in-plane measurements of thin films*

*Out-of-Plane: Ideal for single crystals or out-of-plane measurements of thin films*

*The rotator utilizes a motorized sample rod*




*Co/Pd multilayer sample exhibiting perpendicular anisotropy with the applied field at 3 different angles with respect to the film plane. The observed diamagnetic (-6 x $10^{-4}$ emu/T) background is due to both the silicon substrate and rotator sample holder. Sample provided by Prof. Kai Liu, Georgetown University.*

**Rotator Specifications** (M310)

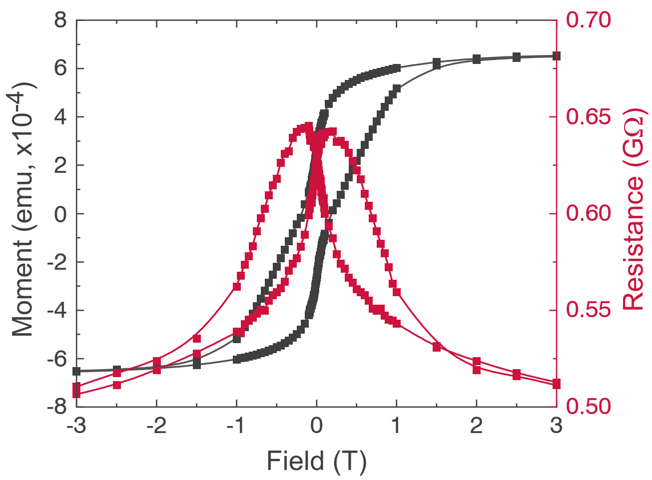
| | |
|---|---|
| Range: | Greater than 500° |
| Angular Step Size: | 0.1° (typical) |
| Reproducibility: | < 1.0° with < 20° backlash (typical) |

Specifications are subject to change without notice.

# Electrical Transport (ETO)

The Electrical Transport Option (ETO) leverages a digital lock-in technique to measure resistance in a traditional Kelvin sensing (4-probe) configuration across a wide dynamic range. This range is extended further by the special 2-probe high-impedance mode for a total range spanning nearly fifteen full decades. Additional functions like I-V curve profiling and differential resistance measurements extend the utility of the ETO to non-ohmic materials as well as device characterization.

Two sample holders are provided with this option for measurements in a parallel magnetic field and perpendicular magnetic field. These specially designed sample holders also allow users to measure magnetic moments while applying a voltage bias to the sample.




*Magnetic moment (black) and resistance (red) measured using the 2-wire high-impedance mode of a $CoFe_2O_4$ colloidal solid. Sample provided by Prof. Jeffrey D. Rinehart, UC San Diego.*

## Electrical Transport Specifications* (M605)

**Resistance**

| | |
|---|---|
| Excitation Mode: | AC |
| Range: | 10 μΩ to 5 MΩ<br>2 MΩ to 1 GΩ (high-impedance 2-probe) |
| Accuracy**: | ± 0.1% typical, ± 0.2% maximum; R < 200 kΩ<br>± 1.0% typical; R ≈ 5 MΩ<br>± 2.0% typical; R < 1 GΩ (high-impedance) |
| Sensitivity: | 10 nΩ RMS typical |

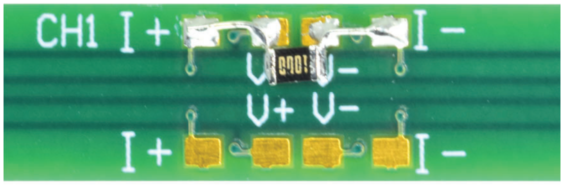
**Drive Parameters**

| | |
|---|---|
| Frequency Range: | 0.1 to 200 Hz (nominal) |
| Current Amplitude Range: | 10 nA to 100 mA |
| Current Amplitude Accuracy: | ± 0.4%, 100 nA drive; improves for larger amplitudes |
| Voltage Amplitude Range: | 10 mV to 10 V (high-impedance 2-probe) |

**Operational Range** 1.8 to 400 K; 0 to 7 T

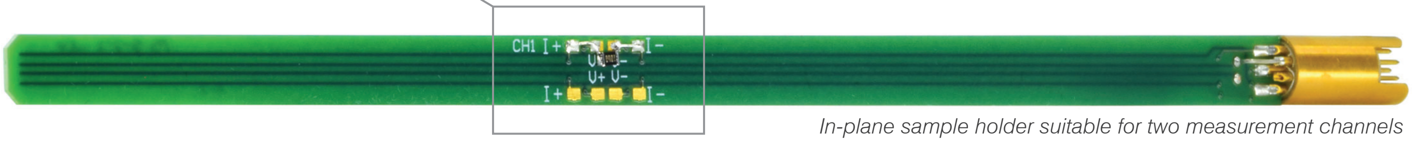
*Values refer to the standard 4-probe configuration and at zero field unless otherwise noted.
**Accuracy specification depends on sourced current and selected preamp range; stated values describe typical performance for a majority of possible measurement configurations.

Specifications are subject to change without notice.




*Test Resistor*

*Out-of-plane sample holder suitable for Hall measurements*



*In-plane sample holder suitable for two measurement channels*

# High Pressure Cell

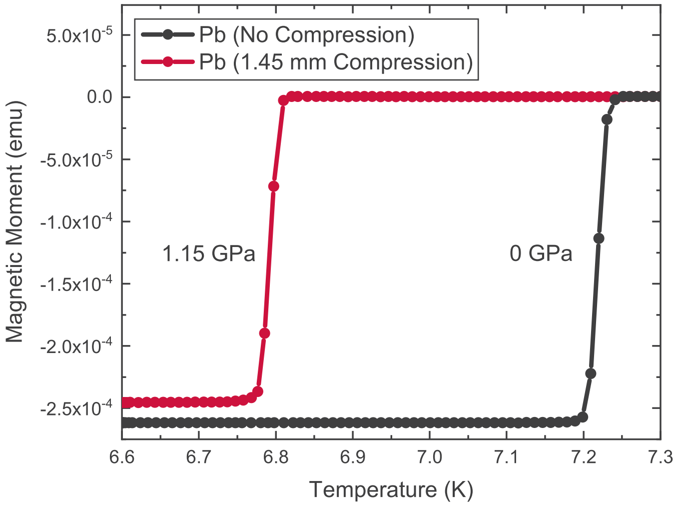
Often a sample's magnetic properties evolve under the application of substantial hydrostatic pressure. The pressure cell option manufactured by HMD, a leading Japanese supplier of pressure cells, offers a simplified design that requires neither copper sealing rings or a hydraulic press to achieve the maximum available pressure of 1.3 GPa. BeCu construction affords a minimized, uniform magnetic background.

**Key Features:**

- Complete kit includes required tools and materials for mounting samples, applying pressure to the cell, and measuring pressure
- Included manometer materials are tin and lead whose superconducting transition temperatures can be used to infer actual cell pressure
- BeCu construction provides minimal background signal and is also compatible with AC susceptibility measurements at suitably low frequencies

*High Pressure Cell*

*Pressure Cell Kit*




*Temperature-dependent magnetization (H = 2 Oe) of elemental lead (Pb) depicting the suppression of the superconducting transition with applied pressure. For a given compression length of the cell the transition temperature can be measured and the pressure calculated using an equation of state.*

## High Pressure Cell Specifications

| | |
|---|---|
| **Pressure** | |
| Maximum Sample Pressure: | 1.3 GPa |
| **Sample Space Parameters** | |
| Diameter: | 1.7 mm, 2.2 mm |
| Length: | 7 mm |
| **Magnetic Moment [*m*]** | |
| Background Signal: | $4 \cdot 10^{-7}$ emu/T |
| **Operational Range** | 1.8 to 400 K; 0 to 7 T |

Specifications are subject to change without notice.

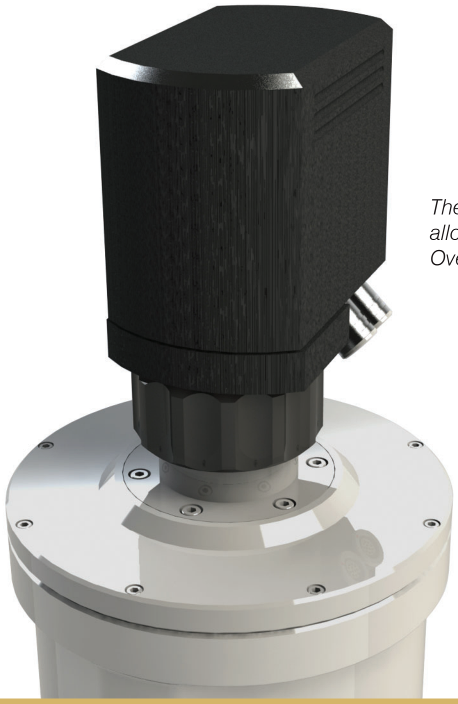
# Compatibilty Table

| Measurement Mode/Sample Holder | Quartz | Brass | Straw | iQuantum | Oven | Rotator | FOSH | ETO | High Pressure |
|---|---|---|---|---|---|---|---|---|---|
| DC Scan | YES | YES | YES | YES | YES | YES | YES | YES† | YES |
| SQUID-VSM | YES | YES | YES | NO | YES | NO | NO | YES† | YES** |
| AC | YES | *** | YES | YES | YES* | NO | YES | *** | * |

†Although magnetic measurements while voltage biasing a sample are possible, the electrical (e.g. resistance) and magnetic properties of the sample should not be performed simultaneously.

*Low AC Frequencies Only; see Application Note 1505-001 for recommendations when using the Oven option.
** Small VSM Amplitudes (< 2 mm)
*** Not Recommended

ULF is Compatible with Every Measurement Mode/Sample Holder.



*The Wire Access Port (WAP) allows connectivity to the FOSH, Oven, Rotator, and ETO.*

Quantum Design, Inc.
10307 Pacific Center Court, San Diego, CA 92121
Tel: 858.481.4400 Fax: 858.481.7410
**www.qdusa.com**
**sales@qdusa | apps@qdusa**

*For complete specifications, contact your local Quantum Design office.
Specifications subject to change without notice. 1500-103 Rev. B0